ELECTRIC WELDING HAZARD TO SPACECRAFT ELECTRONICS *

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Abstract

Electric Welding of spacecraft tubing in the presence of delicate electronics is a necessity on one spacecraft. Because of fears that electromagnetic coupling of weld energy could damage CMOS devices and other sensitive circuits, a test program has been conducted to assess the hazards. An orbital arc welder and an RF brazing machine were measured to determine their likelihood of damaging sensitive electronic equipment. Test parameters were varied to assess the effectiveness of typical EMC practices such as grounding, bonding and shielding. A method of calibrating hazard levels at the victim circuit's location is described along with the results and conclusions of the test program.

Introduction

The assembly process for the Galileo scientific spacecraft to Jupiter will include connecting 1/4" and 1/8" o.d. propulsion propellant tubing in the immediate vicinity of electronics containing CMOS circuitry (Fig. 1). The propulsion personnel have had a successful history of making tubing connections with an automated orbital arc welder, and desired to use it for the Galileo application. The basic welding operation is benign, but the welder uses an estimated 40,000 volt transient spark to initiate the welding arc. The possibility exists that the 40,000 volt spark could couple through cabling into the nearby electronics and damage them. In fact, two electrical anomalies on a prior program were attributed to use of the welder near cabling. A survey of other aerospace companies revealed that one firm embarked on an expensive spacecraft mechanical disassembly process to avoid welding near electronics during a component replacement effort because of a similar concern.

Although the sensitivity of the CMOS electronics was not measured for this program, a prior program determined that a CMOS multiplexer could be damaged at 150 volts and 3 microjoules of energy (Fig. 2). There is now a program requirement that the CMOS must tolerate a 400 volt discharge from a 100 pF capacitor; this is equivalent to 8 microjoules of energy. We have estimated that transient noise voltage and energy on wireing should be below 100 volts and 10 microjoules to prevent damage to the components.

In order to determine how well the welding methods met these requirements, a test program was established to measure the estimated damage potential from the welding system, the effect of modifications to that system, and the effect of various protective measures for the spacecraft circuitry. Additionally, an RF induction brazing system was measured for the same concerns.

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SPIN BEARING ASSEMBLY (SBA) MECHANIZATION

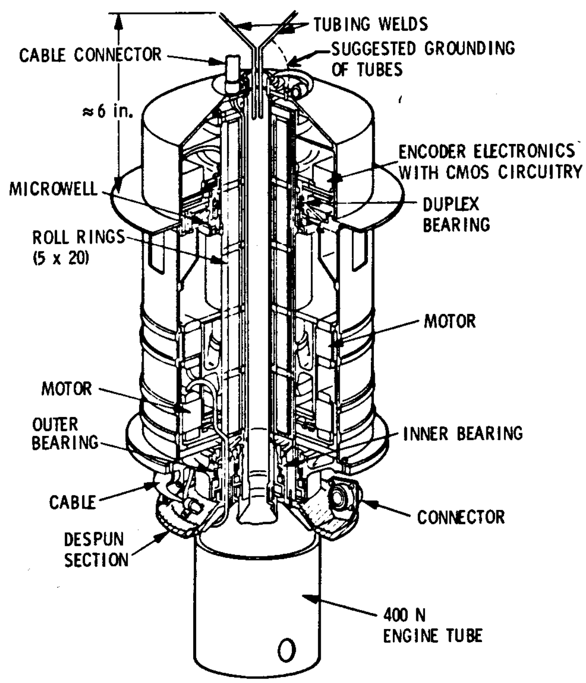

Figure 1. Spin Bearing Assembly and Weld Region

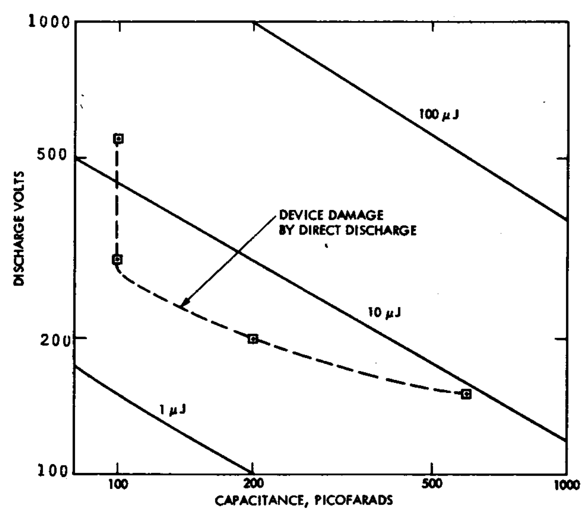

Figure 2. Sensitivity of CMOS Device to Transient Energy

The Welding Equipments

The orbital arc welding system is an automatic tube welder in common use in the airframe and microelectronics industries. A weld head containing an electrode, gear set and motor is clamped over the tubing joint to be welded. The electrode, carrying the arc current, is rotated around the weld joint and a weld current is applied to the electrode in accord with a pre-programmed set of instructions in the weld controller. The welding current and motor current are carried through a wiring bundle connected from the weld head to the controller that may be 20 feet away. Due to the automatic nature of the operation, the welds can be made with uniformly high quality after a weld schedule has been established.

In order to initiate the arc current, an ignition circuit induces a large transient voltage of perhaps 40,000 volts across the electrode to tubing gap of approximately 0.040". During the subsequent weld process a potential of only a few volts is maintained across the arc gap. It is the large initial transient voltage that causes excessive noise to be coupled into adjacent circuitry.

The induction brazing equipment has a brazing head surrounding the tubing to be joined, a controller, and interconnect cabling from the head to the controller. The tubing to be brazed has a close fitting metal sleeve covering the joint area, with the brazing material inside the sleeve. A sinusoidal waveform RF current to the brazing head generates a magnetic field and circulating current in the joint area, heating it and brazing the materials.

The relatively high frequency braze current (500 KHz) radiates magnetic fields which can be induced on nearby wiring.

Initial Measurements

Initially the voltage coupled onto a victim circuit (or some simulation of a victim circuit) was measured with an oscilloscope. After establishing a baseline, several parameters were varied and their effectiveness at reducing the noise voltage determined. Fig. 3 shows the first test configuration, which measured the voltage coupled onto the tube being welded, with respect to a separate ground.

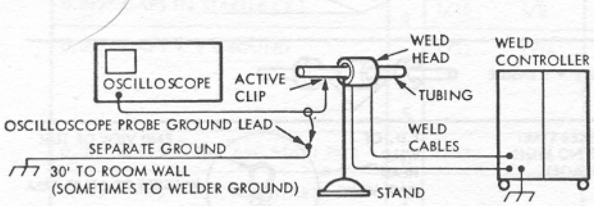

Figure 3. Basic Voltage Test

Figure 4 shows two typical photographs of noise measured by that method. The voltages can be seen to be in excess of ± 400 volts, which certainly can be damaging to CMOS. Unfortunately the welding arc start process was so variable that the voltage measurement was an imprecise, inadequate, and non-repeatable measure of the stray energy or voltage from the arc start process.

A test method using standard fuses was next investigated to measure arc initiation damage potential. It proved to very effective.

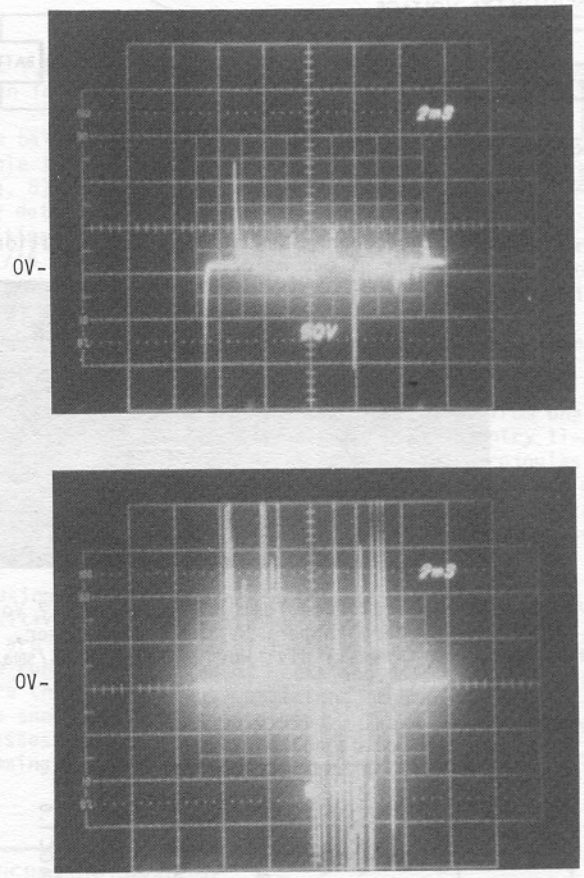

Figure 4. Typical Arc Start Voltage Transients on Tubing near Welds. (Vertical 50V/small div; horizontal 2 mS/small div)

Fuse Energy Sensitivity

To assess the hazard to spacecraft electronics, fuses of the AGX, 3AG, and AGC variety were used in the test configuration near the welder. Fuse values ranged from 1/200 Amp to 1 Amp. It was found that, for any given test condition, the fuses were a very repeatable measure of the damage potential from the welder; i.e., a 1/100 Amp fuse would always blow, but the 1/32 Amp fuse would not. Although this method does not define the exact energy or voltage delivered to the fuse, the energy could be bracketed to an extent that was useful for subsequent data analysis.

The fuse energy sensitivities were calibrated using the test configuration of Fig. 5. The voltages used ranged from 12 to 36 volts. A more refined test would have tested over a wider range of voltages, especially higher ones, but it was not feasible with the instrumentation available. It was assumed that the applied energy was in the constant energy region of the fuse and larger voltages would have yielded similar energy values; this was true for the 3:1 range of voltage that was used. A typical set of waveforms (voltage and current) is shown in Fig. 6 for a 1/8 Amp fuse tested in this manner.

The energy was computed as the time integral of voltage times current, and the results are shown in Fig. 7.

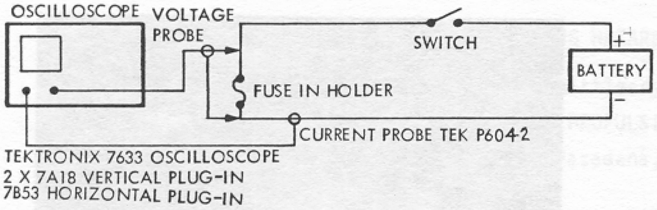

Figure 5. Fuse Energy Sensitivity Configuration

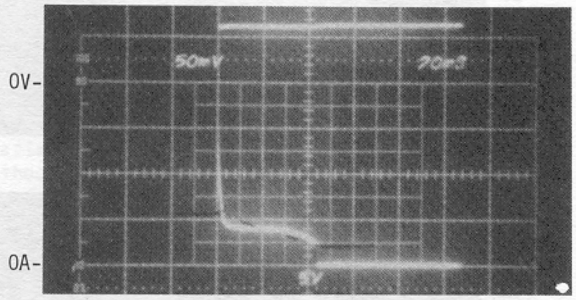

Figure 6. Typical Fuse Test 1/8 Amp Fuse, 12 Volt Battery (upper, 5V/small div; lower, 0.1A/small div; Horizontal, 20 mS/small div)

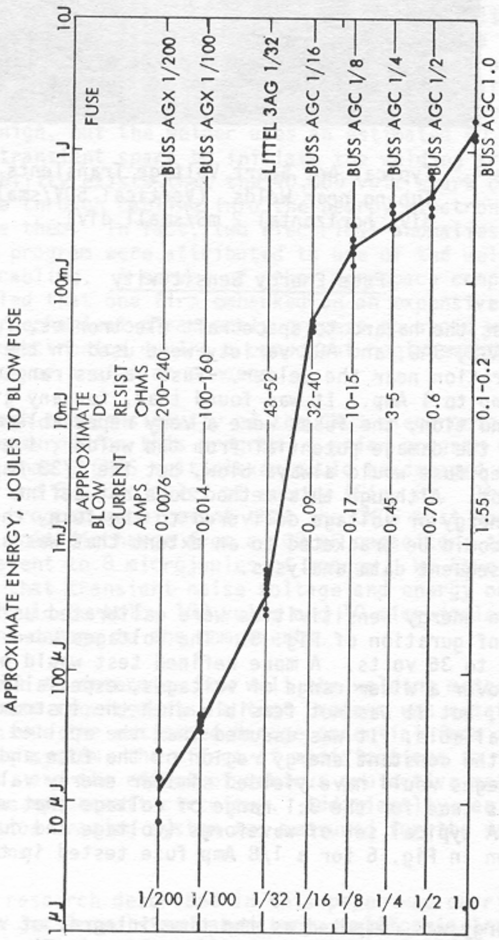

Figure 7. Fuse Energy Sensitivity, Approximate

Tests Performed

Two types of tests were performed; those modifying the arc welder as a noise source, and those modifying the victim configuration.

The following methods (depicted in Fig. 8) were tested to determine their effectiveness at reducing arc welder transients:

a) Adding a separate "Y" ground on either side of the weld head.

b) Adding an RF inductor (choke) on either side of the weld head.

c) Using a "whisker" arc initiation instead of the transient arc method (the whisker is vaporized by the weld current, leaving a plasma to initiate the arc).

d) Reducing the internal (inside the controller) spark gap to reduce the spark voltage.

e) Reducing the spark power adjust (inside the controller). This is a series resistor in the arc start circuit.

f) Not shown, use 12° electrode tip vs the standard 20° tip (on the theory that more pointed electrodes break down at a lower voltage).

Various combination of grounding and isolation as shown in Fig. 9 were tested to assess the effects of victim circuit configurations.

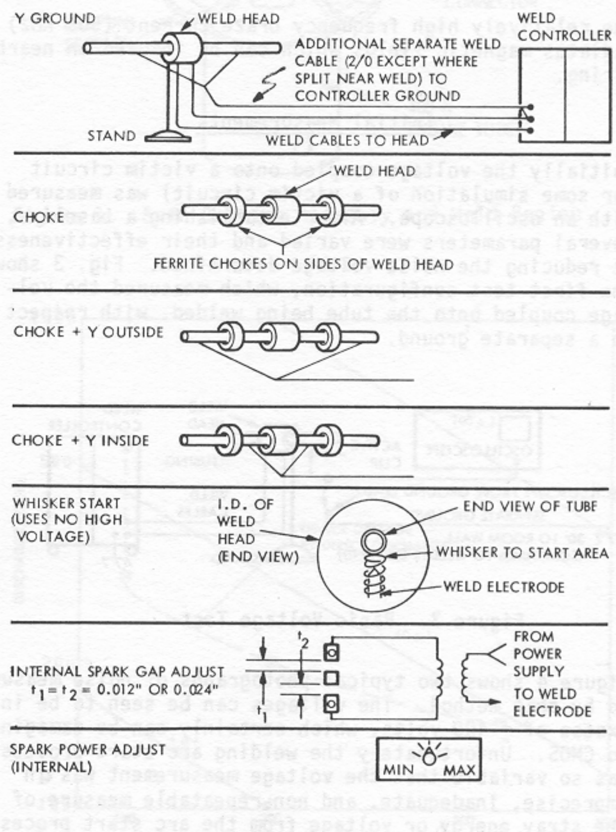

Figure 8. Possible Weld Transient Control Methods

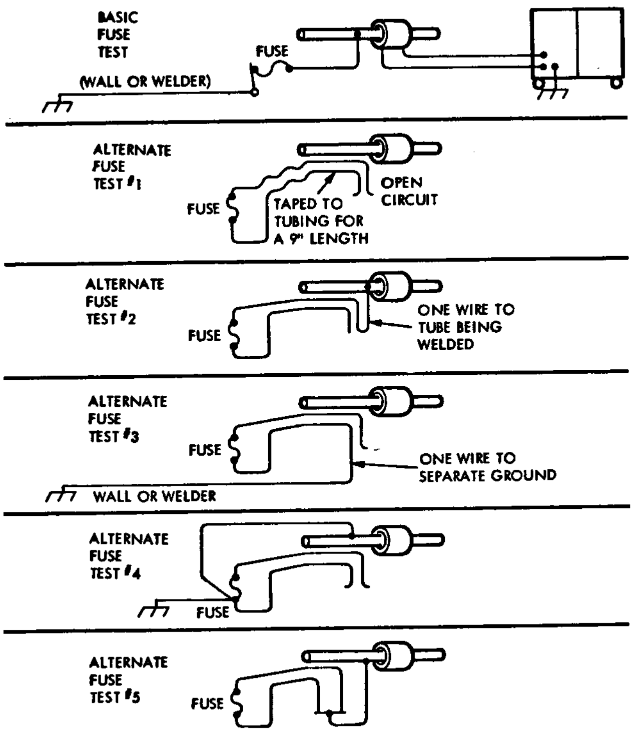

Figure 9. Weld Transient Victim Test Configurations

Results and Analysis, Arc Welder

The 1.5 microhenry inductors performed no useful function in these tests.

The balance of the arc welder test results are shown in Table I. For each welder configuration (described in Fig. 8) and victim configuration (described in Fig. 9), the data entered are the two fuse ratings bounding the critical energy. For example, in the 1-A table entry a 1/16 Amp fuse always blew due to the arc start process, but a 1/8 Amp fuse never did. Referring to Fig. 7, this indicates that this configuration delivered between 48 and 180 millijoules of energy to the fuse (using nominal measured values).

To analyze the arc welder data, the entries from one box to another are compared. For example, entry 11-A indicates between 40 microjoules and 400 microjoules of energy is available to blow the fuse. Thus, use of the .012" gap, 12° tip, and 75% arc start power improves matters at least a factor of 120 in energy, and perhaps as much as 4500X in this configuration.

By using extreme (not nominal) measured values for fuse sensitivity and by examining all the tabular entries, the arc welder results of Table II were obtained. Tests were run over a period of weeks and different setups; where the data are not consistent, the most conservative energy estimates were used. Table II also makes an assessment of the hazard threat to CMOS circuitry, assuming a sensitivity of 8 microjoules.

WELDER CONFIGURATIONS		VICTIM CONFIGURATIONS											
		BASIC FUSE TEST TUBE-FUSE-GND (A)		ALTERNATE #1 FLOATING (B)		ALTERNATE #2 ONE WIRE TO TUBE (C)		ALTERNATE #3 ONE WIRE TO GROUND (D)		ALTERNATE #4 ONE FUSE WIRE TO TUBE AND GND (E)		ALTERNATE #5 BOTH WIRES TO TUBE (F)	
		BLO	NO BLO	BLO	NO BLO	BLO	NO BLO	BLO	NO BLO	BLO	NO BLO	BLO	NO BLO
NORMAL (NO SPECIAL GROUND, 2 X 0.025" GAPS, MAX ARC START POWER, 20° TIP ANGLE)	1	1/16	1/8		1/200	1/32	1/16	1/32	1/16				
Y GROUND	2	1/16	1/8			1/100	1/32	1/100	1/32				
WHISKER START (0.003 NiCr)	3	1/200	1/100										
0.012" GAPS IN STARTER CKT	4	1/16	1/8			1/100	1/32	1/100	1/32				1/200
0.012" GAPS + Y GROUND	5	1/32	1/16					1/100	1/32			1/200 NOT TEST-ED	1/100
0.012" GAPS + 75% ARC START PWR	6	1/32	1/16					1/200	1/100		1/200		1/200
0.025" GAPS + 75% ARC START PWR	7							1/100	1/32				
NORMAL PLUS 2X 0.012" GAP, 12° ELECTRODE TIP	8	1/16	1/8										
0.012", 12° TIP, 50% ARC START POWER (RARELY STARTED)	9		1/16										
0.012", 12° TIP, 75% POWER	10	1/32	1/16										
0.012", 12° TIP, 75%,Y GROUND	11	1/100	1/32										

Table I. Summary of Major Test Results - GLL Weld Transient Study
Size of Fuse (Amps) Which Blows (Blo) or Not (No Blo) Under Specified Conditions

TABLE II

ESTIMATED DESTRUCTIVE ENERGY AT SENSITIVE ELECTRONICS DUE TO GALILEO ORBITAL ARC WELDING OPERATIONS

Energy Available (Basic Fuse Test)	130 millijoules
Effect of arc start gap reduction to .012"	2.2-2.6 X
Effect of 75% arc start power vs. max.	2.2-2.6 X
Effect of "Y" ground	1.4-11 X
Effect of Location in SBA wiring (Test AFT #3 vs. BASIC)	178-209 X
Effective of applying a grounding connector for all SBA electronics (Test Fig. 9 test 5 vs. Fig. 9 test 3)	8-(∞)
Net maximum energy at electronics	<1 to 13 microjoules
Worst-case sensitivity of electronics	8 microjoules
Safety Margin	>+8 x to 0.6 X (good) (not good)
Additional Factors not considered:	
Actual sensitivity of electronics:	unknown, but less sensitive than 8 microjoules.
Attenuation of SBA housing:	unknown, but helpful
Additional grounding of SBA electronics compared to AFT #5	unknown, but helpful

Results and Analysis, Brazing Machine

It was not possible to blow the 1/200 Amp fuse in any of the configuration shown in Fig. 9. It was found possible, however, to blow a 1/32 Amp fuse (but not a 1/16 A) by placing a 7" diameter loop of wire with three turns, as close as possible to the brazing head. The open circuit voltage recorded on the loop was 40 volts under the same conditions. At 2" distance, a 1/200 Amp fuse could not be blown.

Conclusions and Recommendations

The induction brazing machine that was tested appears to be unconditionally safe for use near sensitive CMOS electronics.

Orbital arc welding is permissible if precautions are observed before the welding operations take place.

These treatments and precautions include:

a) Adjustment of the welder internal arc start gap to 0.012" (two places).

b) Use of minimum arc power (75%) needed to provide adequate start.

c) Attachment of a 2/0 or heavier gage "Y" ground to the tubing being welded on either side of the weld head, and return of it to the welder ground. The ground cable is to be the same length as the welder cables and routed with them from weld head to welder ground.

d) Attachment of a special connector cap to the spin bearing electronics connector. This connector cap is to short every pin to each other and to the cap, which is to have a conducting end piece to shield the whole assembly, and it is to be attached (grounded) to the adjacent SBA structure.

e) Grounding of the tubing being welded to the SBA at a point on the same end of the SBA at the welding is being performed, as near as possible, with as short a ground strap as possible.

f) Incorporation of visual inspection of the weld equipment for good condition in addition to operational checkout prior to test time.

g) Use of 12° electrodes.

Although the nominal risk assessment indicates little or no safety margin, the conservatism in the data analysis gives assurance of a safe weld operation.

Acknowledgement

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